Deep Trench with field plate (DT FP) MOST die edge termination.

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Abstract. This paper presents a simulation study of novel die edge termination that is a combination of floating wells and Junction Termination Extension (JTE). Device is simulated within realistic manufacturing parameters in order to study the possible device realization. It is concluded that for a given structure a breakdown voltage 400 V is achievable with good tolerance for process flow variations.

Introduction.

A vertical semiconductor power device includes a plurality of semiconductor power cells having a drain disposed at a bottom of a semiconductor substrate. Each of the cells includes a gate surrounded by a body region encompassing a source region.

The super-junction transistor is based on the concept of charge compensation across a PN junction made of alternatively stacked, heavily doped N and P regions (pillars or columns) and relaxation of the peak electric field by diverging into three dimensions.

The super-junction concept, while elegant and amazingly simple in principle, is extremely difficult and challenging to realize in practice. This is due to the requirement of forming three-dimensional device structures with a high aspect ratio.

Furthermore, the super-junction MOST has shown some undesirable secondary effects that are not observed in the conventional power MOST. Two notable examples are the poor reverse recovery characteristic of the body diode [1] and the degradation of the forward biased safe operating area (FBSOA) due to a "secondary breakdown" effect [2], both caused by the unique super-junction device structure. Solution for reverse recovery performance of the body diode was issued at [3].

The charge balance in Trench MOST with field plate is actually maintained between the single crystalline silicon N pillar and the polysilicon vertical capacitor. LPCVD polysilicon deposition is used to refill the trench. A unique advantage of Trench MOST is that its trench field plates do not directly participate in the operation of the MOST body diode, and therefore may not cause the mentioned poor reverse recovery characteristics and second breakdown phenomena, as in the case of other SJ MOSFET structures. The Si/SiO2 interface charges and oxide thickness are expected to have a considerable influence on the breakdown voltage.

In addition to active cell development, die edge termination has also a significant impact on device performance [4].

Deep Trench Cell Design.

Cell design must provide a desired breakdown voltage for a given geometry. For superjunction and deep trench devices depletion zone initially propagates laterally and after that vertically. The basic condition for deep trench devices lateral depletion is that field strength reaches its critical value after complete depletion only. That means N-drift region has maximum doping density level. Doping densities theoretical limits for trench and wells structures are shown at the Table 1, respectively.

Table 1: Deep Trench structures maximum epi doping.

Topology and technology	Maximum epi doping.	Cp=Wtr=12 um
Filled trench, stripe topology	$N_d \leq E_{crit} \cdot \varepsilon_{si}/q \cdot (C_p - Wtr)$	**Nd<2.7E15 cm^{-3}**
Filled well topology	$N_d \leq 2Cp \cdot E_{crit} \cdot \varepsilon_{si}/q \cdot (C_p - Wtr)^2$	**Nd<5.4E15 cm^{-3}**

Filled well cell design was usedfFor BV simulation. Parameters are: cell pitch Cp=12 um, trench width Wtr=6 um, trench depth Dtr=26 um, that gives trench aspect ratio AR=4.3. Sidewall field oxide thickness is 2 um. In order to prevent field plate induced breakdown field plate depth optimisation was done, optimal depth with a given parameters is 18 um. Simulated cell breakdown voltage has value 549 V.

It has to be noted, that cell BV degrades with N- drift doping density and field oxide thickness variations. Therefore N- drift doping density has to be chosen with taking into account such restrictions. From the other hand that doping has to be higher enough to bring advantages in comparison with conventional MOST.

N-drift region specific resistance estimation.
For conventional MOST.
Drift region doping density Nd=7E14 cm^{-3} , specific resistance ρ=6.33 Ohm ·cm, thickness d=28 um gives specific resistance:

$$Ron \cdot A = 17.7\ mOhm \cdot cm^2$$

For Deep Trench with field plate MOST.
Drift region doping density Nd=2E15 cm^{-3}, specific resistance ρ=2.31 Ohm ·cm, thickness d=26 um and geometrical factor $F=1-W^2tr/C^2p=0.75$ gives specific resistance:

$$Ron \cdot A = 8\ mOhm \cdot cm^2$$

3D structure description.

A floating trenches and Junction termination extension (JTE) structure combination was used for simulation. Structure size is 6x70x28 um. JTE width is 40 um. First trench is under potential U= 0 V, following trenches are floating. Silicon and doping structure used for BV simulation is shown at Fig. 1, oxide is removed. Junction Termination Extension junction depth is Xj=5 um.

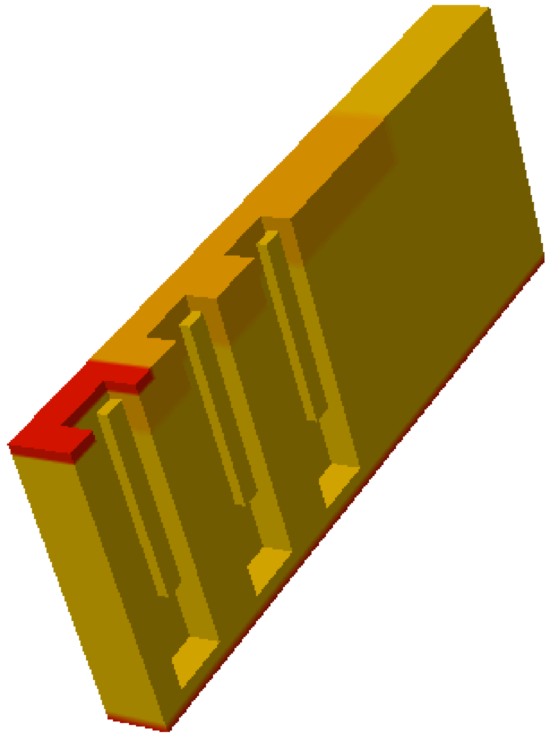

Fig.1. 3D simulation silicon and doping structure, half-cell pitch, field oxide is removed.

3D structure simulation results.

For a given structure breakdown voltage (BV) simulations with JTE doping variations were done. BV curve has a maximum that depends from JTE parameters: doping density, width, junction depth and field oxide (FOX) fixed charge (Fig. 2).

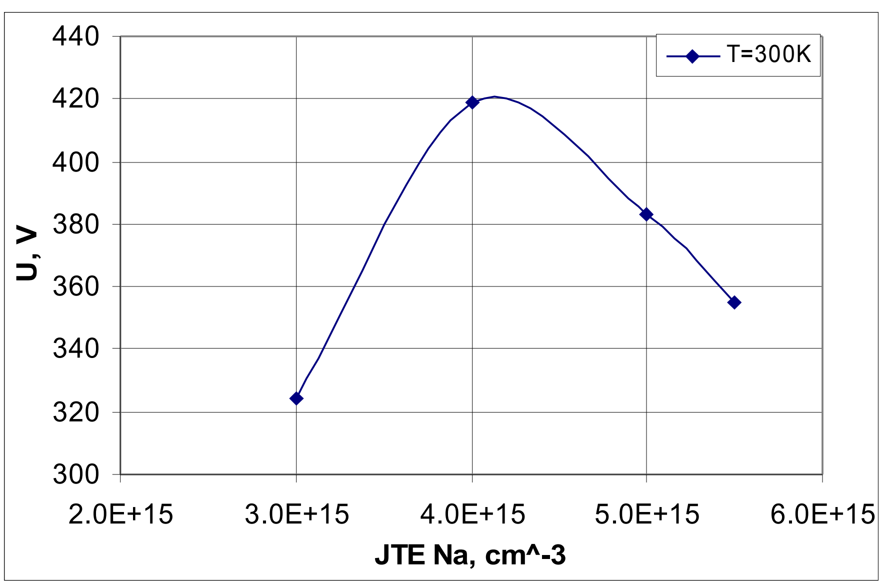

Fig. 2. Optimal JTE doping density, Xj= 5 um, width 40 um.

Breakdown I-V curve is shown at Fig. 3.

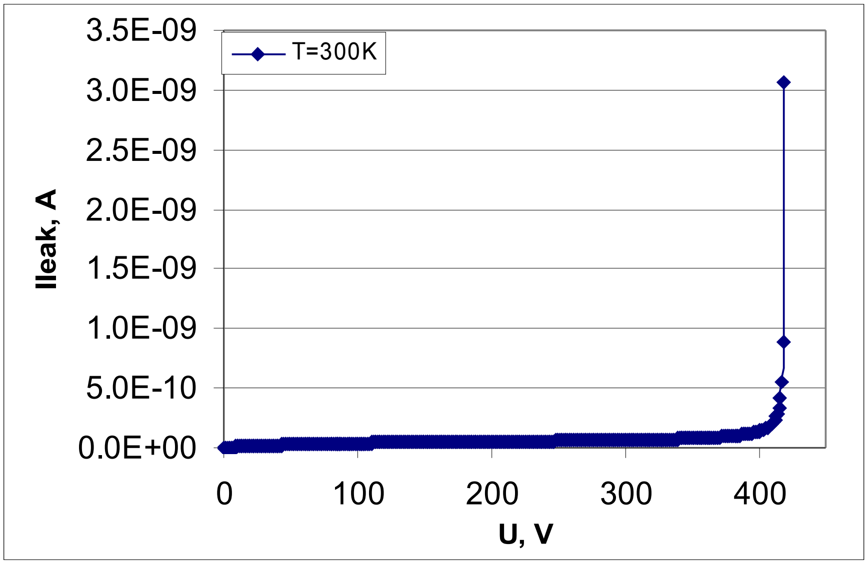

Fig. 3. Breakdown I-V curve, Xj= 5 um, width 40 um.

Potential distribution is shown at Fig. 4, 2D view from trench side, and 3D view from the opposite side Fig. 5.

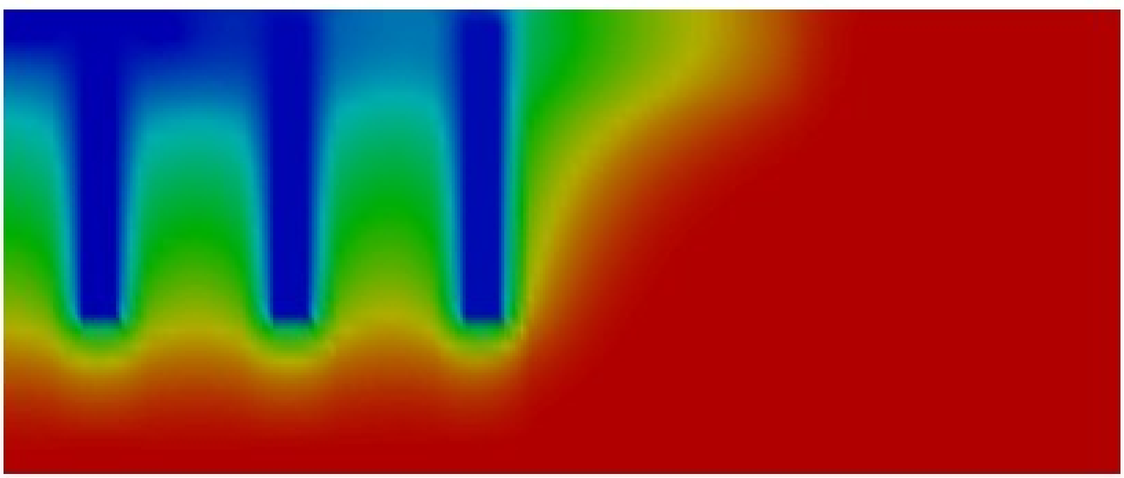

Fig. 4. Potential distribution at U=419 V, JTE Na=4E15 cm^{-3}.

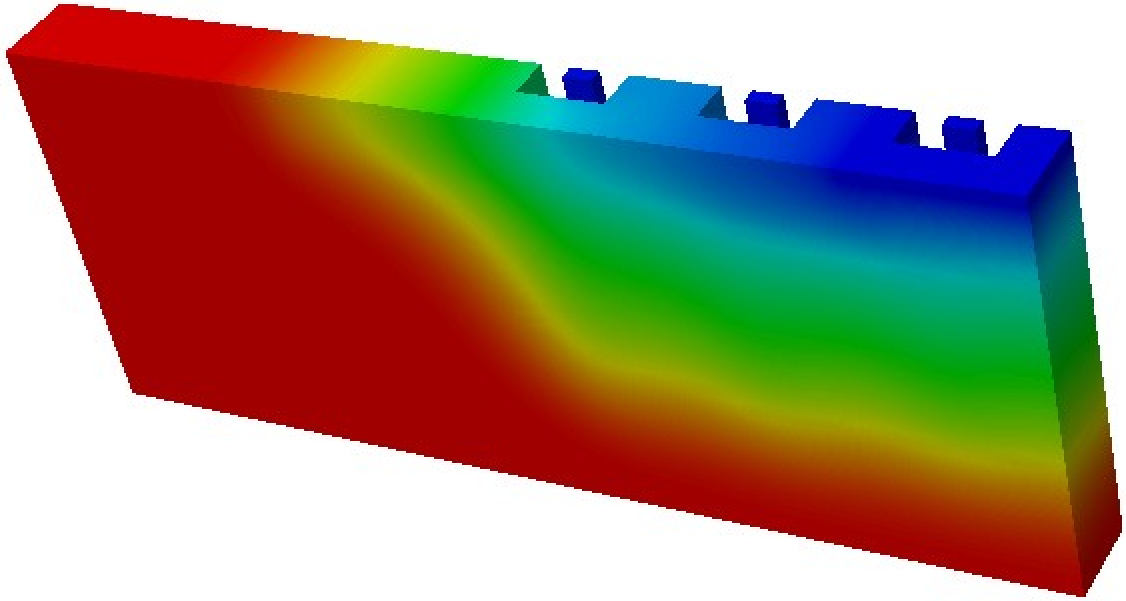

Fig. 5. Potential distribution at U=419 V, JTE Na=4E15 cm^{-3}, 3D view.

Discussion.

Optimisation for JTE width was not performed at the moment. Termination structure BV currently is 93.3% active cell BV and in terms of increasing voltage optimisation cannot bring a much improvement. In terms of switching losses such optimisation is desirable, but it demands transient analysis simulation.

Further development can be done in terms of decreasing Ron·A down to 5.33 mOhm·cm^2 by increasing N-drift doping density to 3E15 cm^{-3}. But it could be a technology challenge in terms of manufacturability and yield.

Conclusions.

A combination of floating trenches (wells) and JTE structure as a die edge termination had been simulated. 3D simulation gives termination breakdown voltage as high as 93.3% cell BV. Simulated structure has a realistic parameters set and can be realised at practice.

References.

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